Optical Manipulation of Magnetism

in

Correlated Electron Systems

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Thanks to Koshihara, Okimoto, Iwai

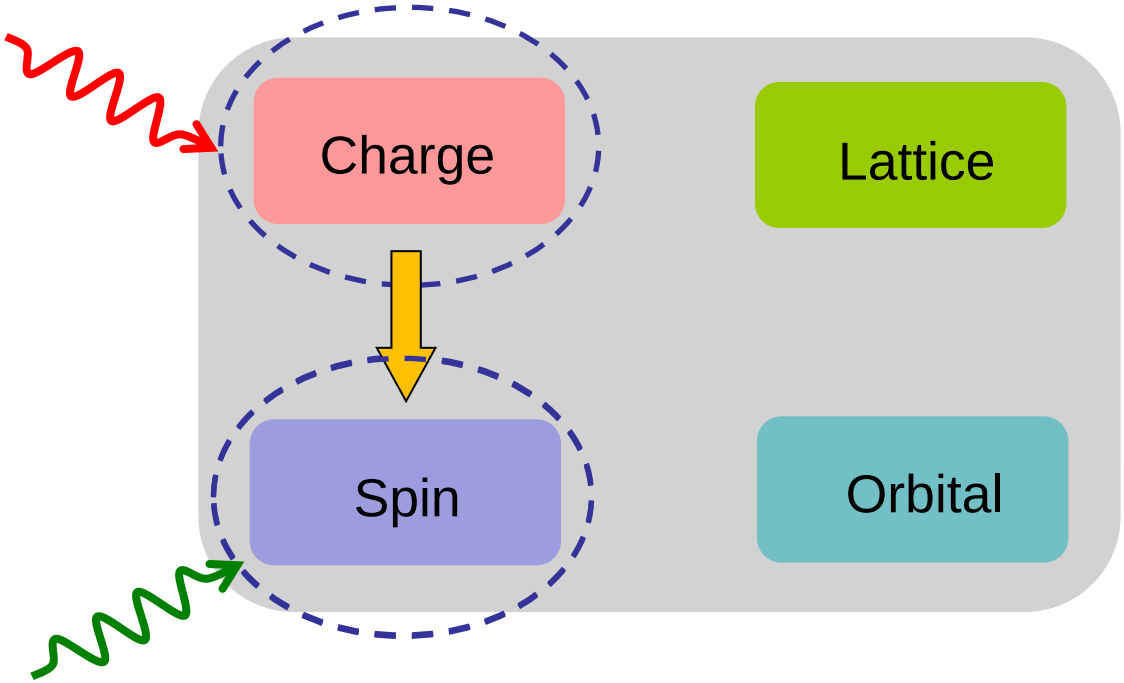
IMPACT @ Paris-sud, Orsay
September 10-14, 2012

TOHOKU UNIVERSITY

Spin-charge coupled system

Optical manipulation of magnetism

in spin-charge coupled system

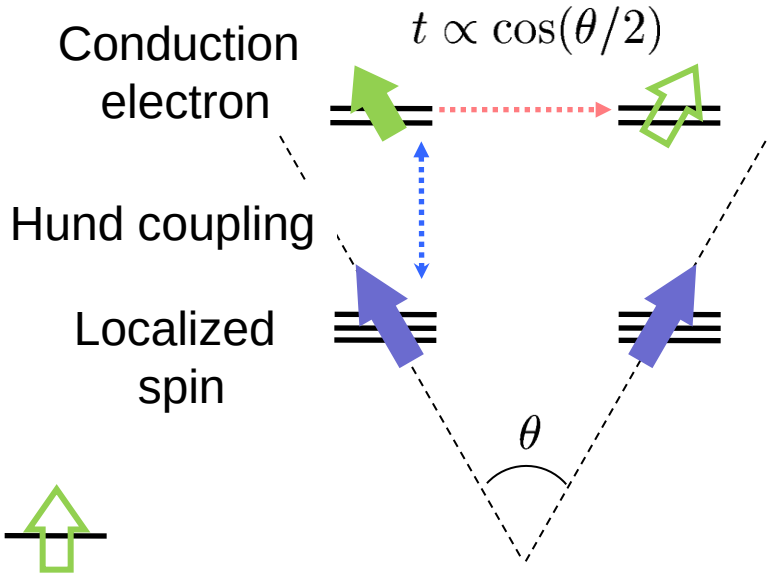


Circular polarized light

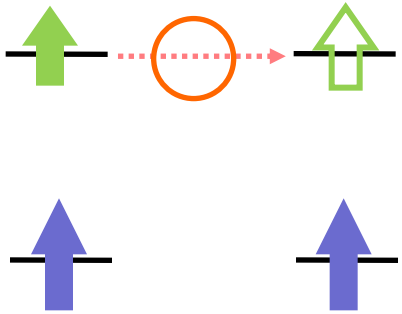
Spin-orbit coupling

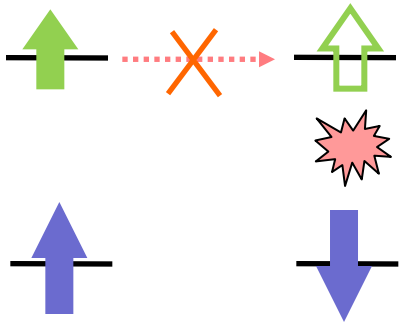
Double exchange interaction

Zener (‘51), Anderson-Hasegawa (‘55), de Gennes (‘59)



Conduction
||
Magnetism





Present talk

Spin-state transition (Cobaltites)
Inverse Double-exchange phenomena (Manganites)

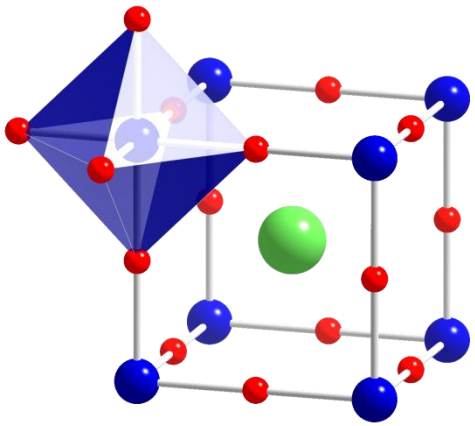
Photo-induced HS bound state

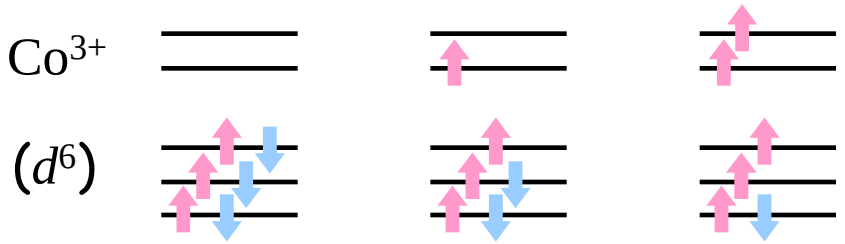
in spin-transition system

(Cobaltites)

Perovskite cobaltites

$LaCoO_3$





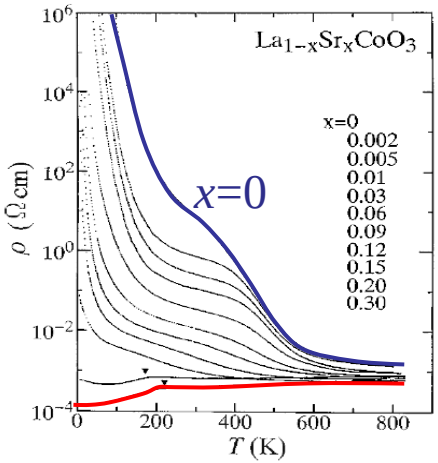
Crystalline field splitting

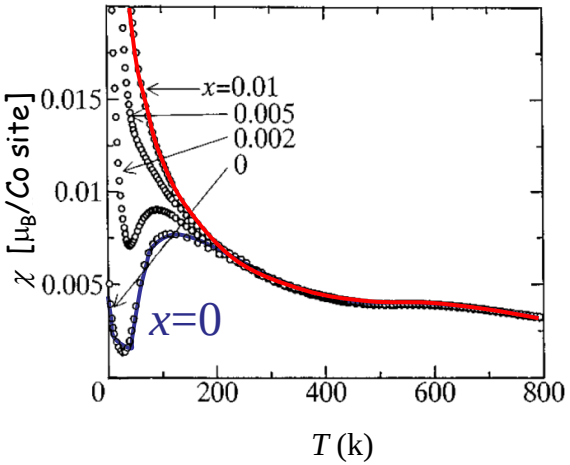
Δ

Hund coupling

J

Spin transition by temperature, and doping

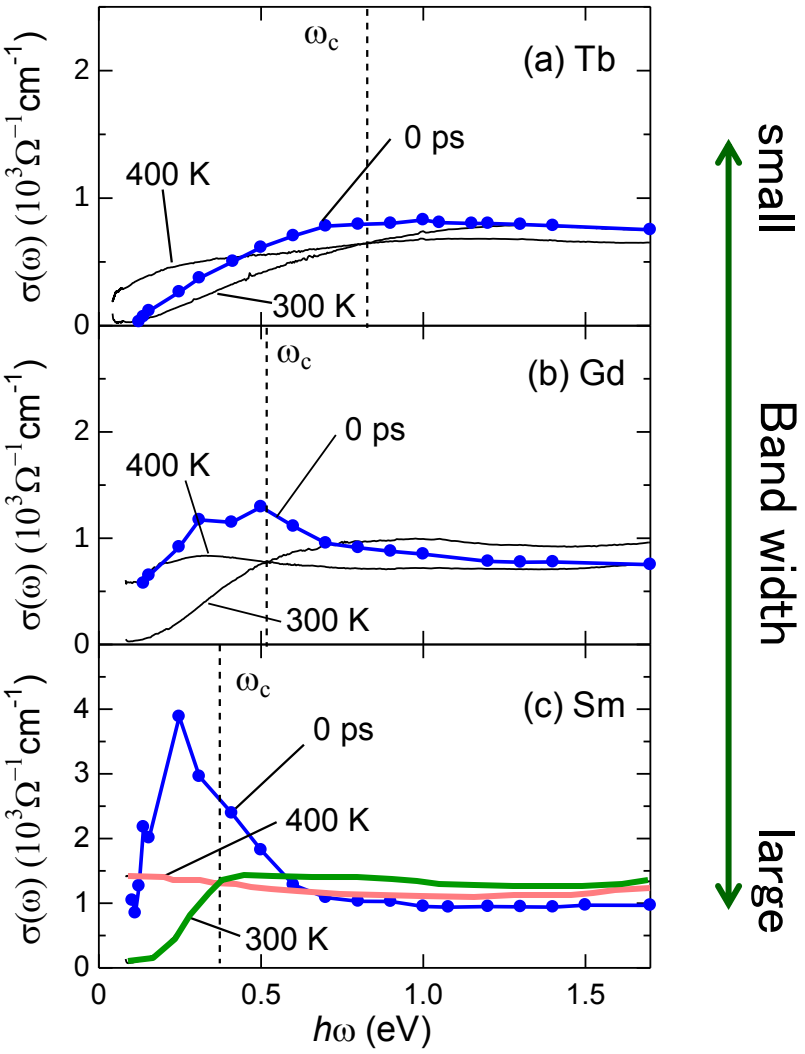




Y. Tokura *et al.* Phys. Rev. B (‘98)

Photo irradiation

$$RBaCO_2O_6 \ (R = Tb, Gd, Sm)$$



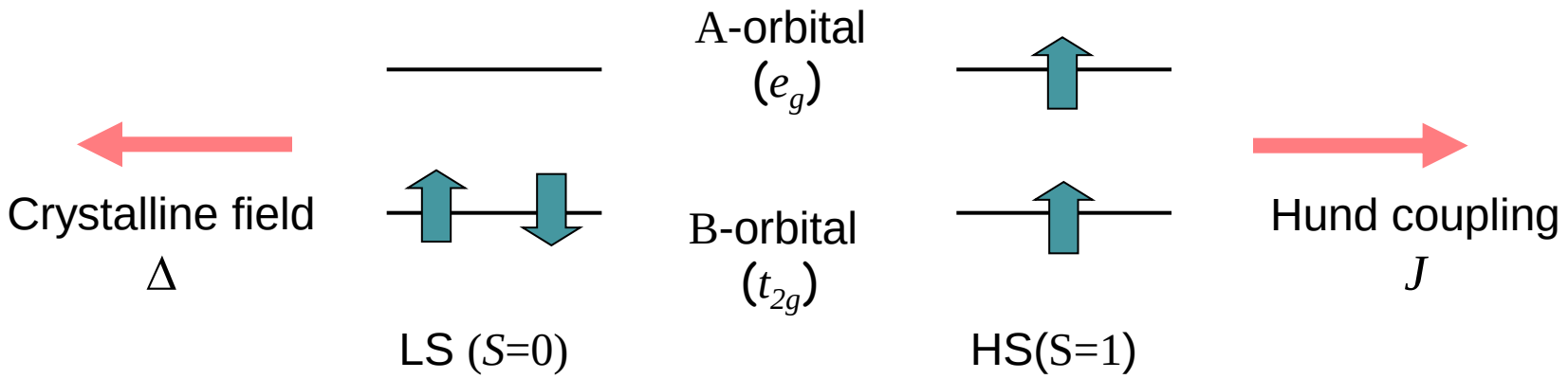
Prof. Koshihara's talk

- Non-magnetic insulator
  ⇨ Metallic
- Photo excitation
  ⇕
  Thermal excitation
- *R*-ion (band width) dependence

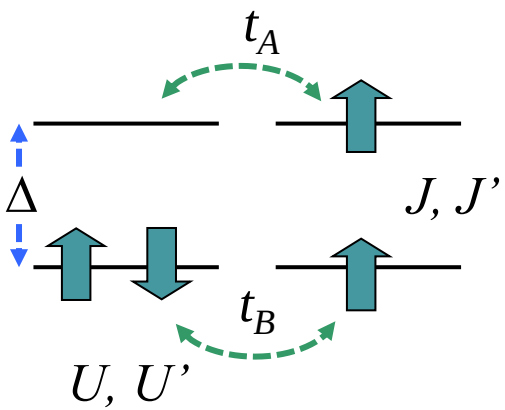
Y. Okimoto, S. Koshihara et al. Phys. Rev. B ('11)

Also Prof. Iwai's talk for $LaCoO_3$

Theoretical model



$$\begin{aligned}\mathcal{H} &= \Delta \sum_{i\sigma} c^{\dagger}_{iA\sigma} c_{iA\sigma} - \sum_{\langle ij\rangle\gamma\sigma} t_{\gamma} \left(c^{\dagger}_{i\gamma\sigma} c_{j\gamma\sigma} + H.c. \right) \\ &+ U \sum_{i\gamma} n_{i\gamma\uparrow} n_{i\gamma\downarrow} + U' \sum_{i\sigma\sigma'} n_{iA\sigma} n_{iB\sigma'} \\ &- J \sum_{i\sigma\sigma'} c^{\dagger}_{iA\sigma} c_{iB\sigma} c^{\dagger}_{iB\sigma'} c_{iA\sigma'} - J' \sum_{i\gamma} c^{\dagger}_{i\gamma\uparrow} c_{i\bar{\gamma}\uparrow} c^{\dagger}_{i\gamma\downarrow} c_{i\bar{\gamma}\downarrow},\end{aligned}$$

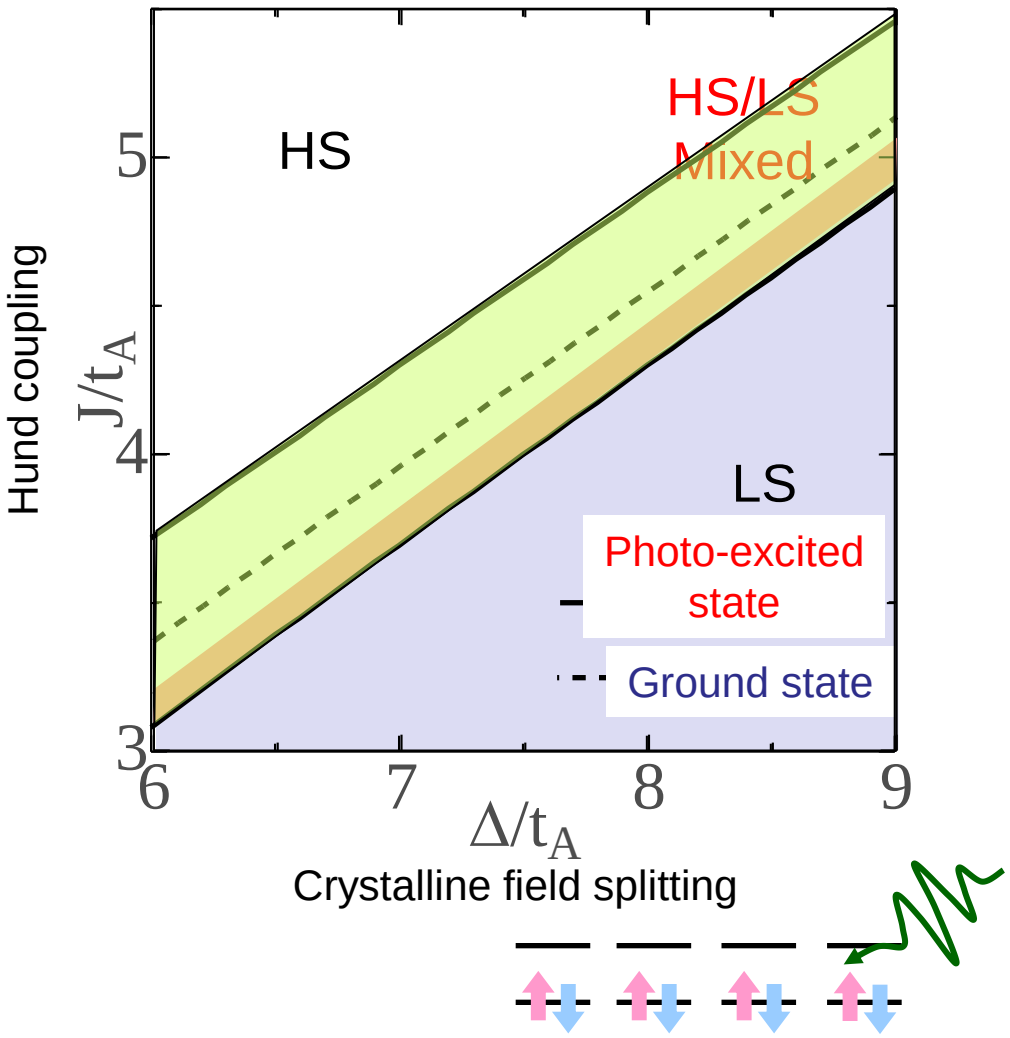


Ave. electron # /site＝2

Exact diagonalization & t-dependent HF

R. Suzuki, T. Watanabe and SI, Phys. Rev. B 80, 054410 (2009)

Photo-induced spin state change

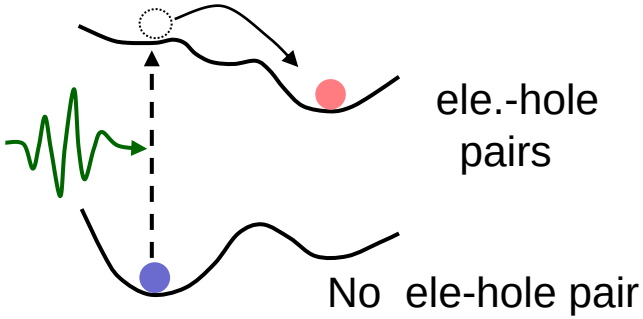


- LS band insulator

LS/HS mixed state (metal)

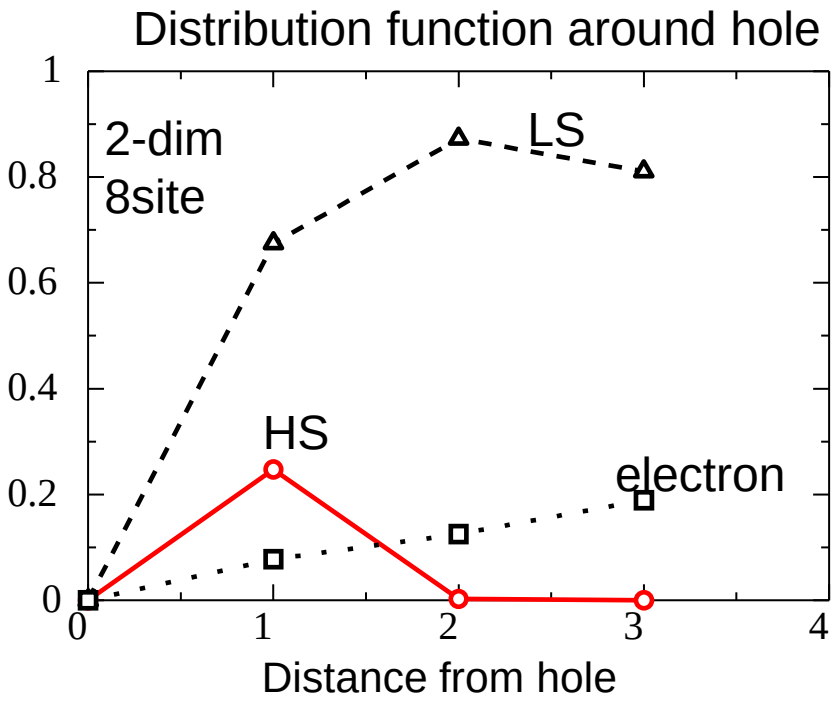
Photoinduced spin state change

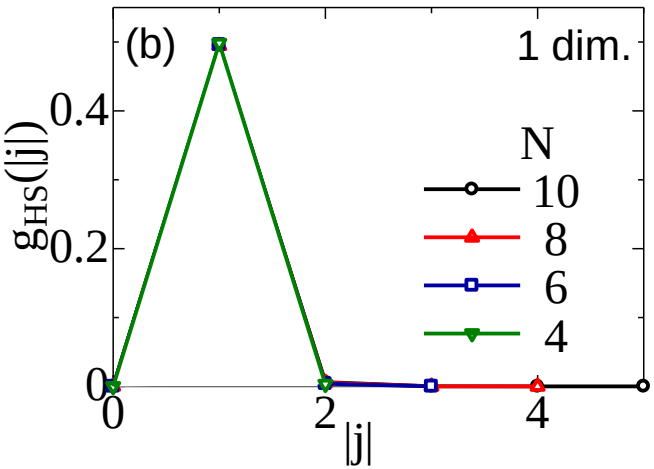
- Lowest energy state
  in photo-excited state
  (one ele.-hole pair in N site)

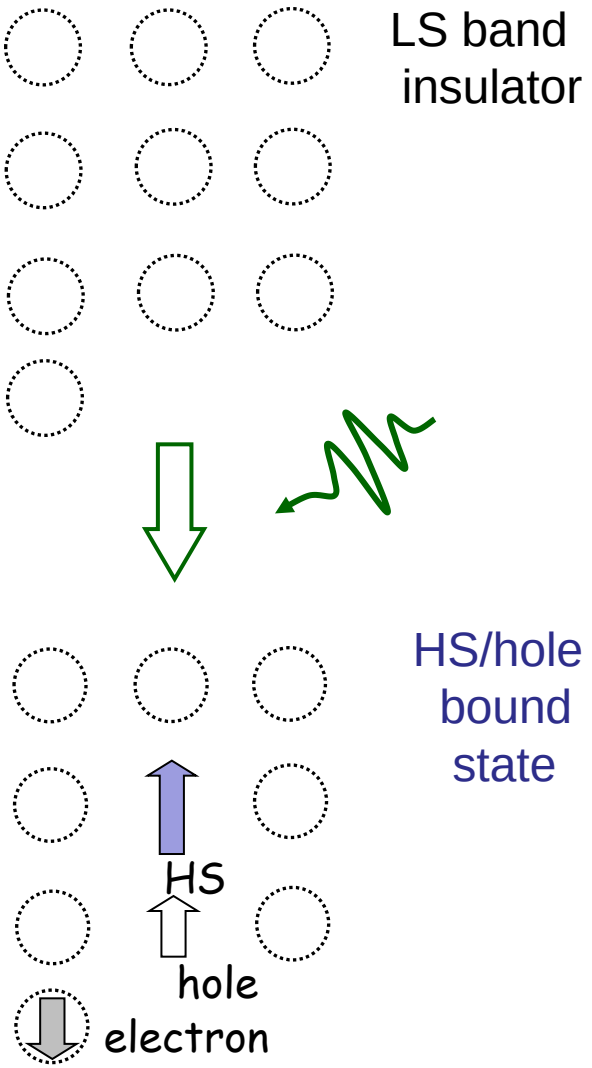


Y. Kanamori, H. Matsueda and SI, Phys. Rev. Lett. 107, 167403 (2011)

HS/hole bound state

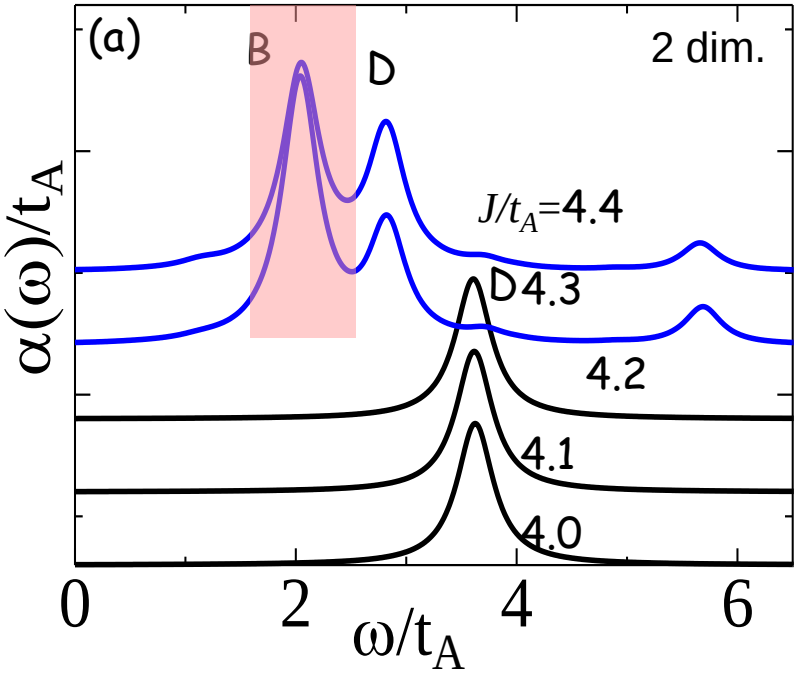






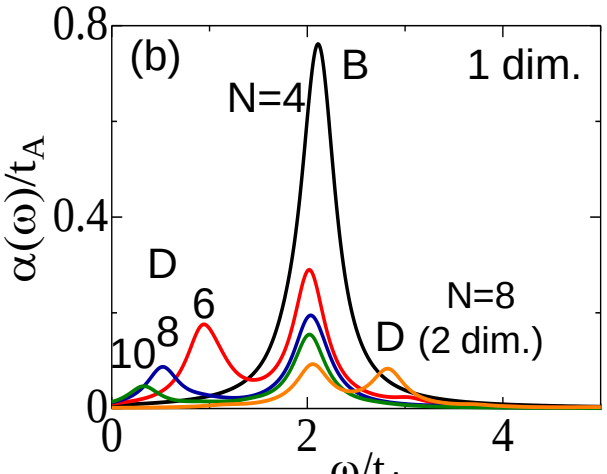
Y. Kanamori, H. Matsueda and SI, Phys. Rev. Lett. 107, 167403 (2011)

Optical pump-probe spectra



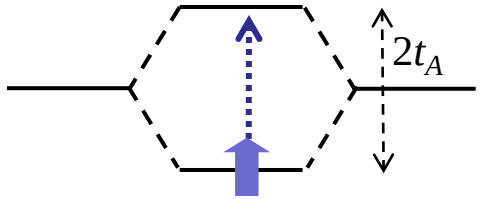
Photoinduced spin-state transition

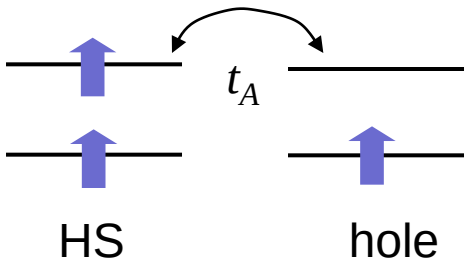
No spin-state transition



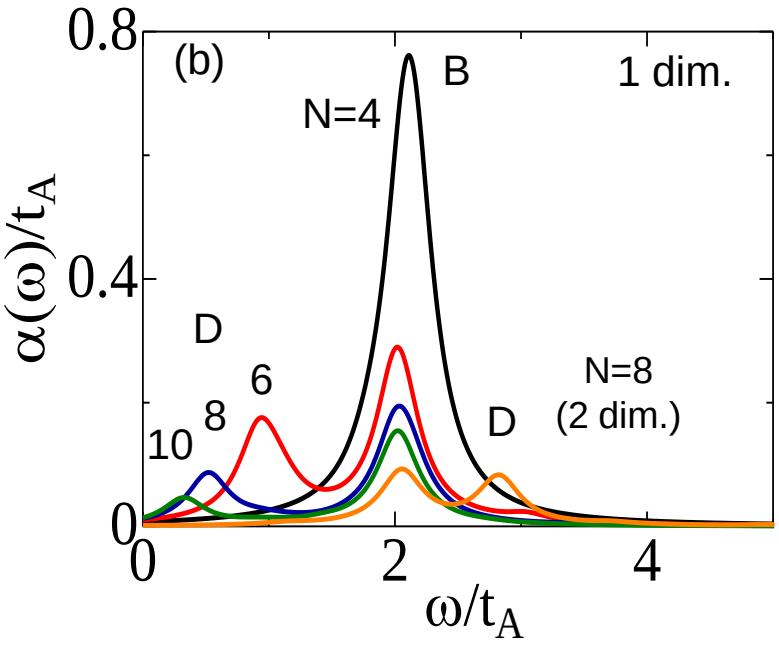
- A unique peak structure in photo-induced spin-state transition phase

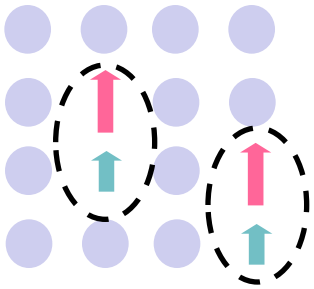
Excitation inside of HS/hole bound state



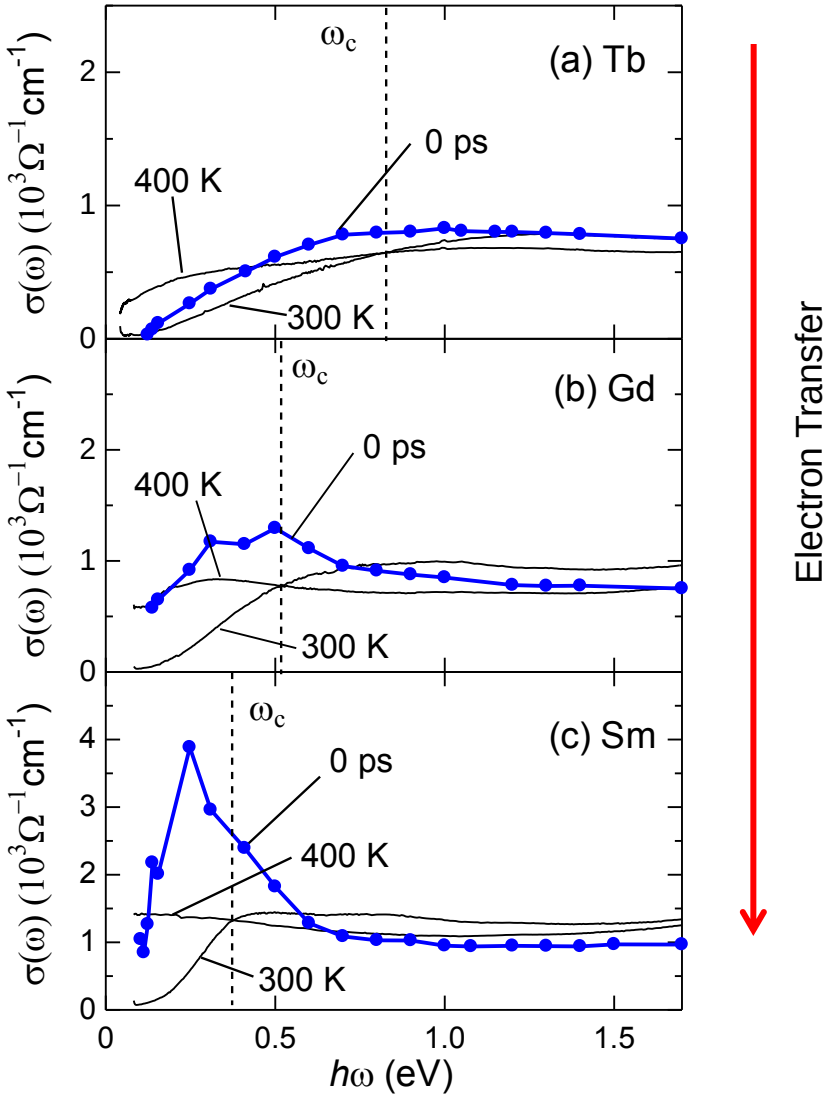


Implication for experiments





$RBaCO_2O_6$



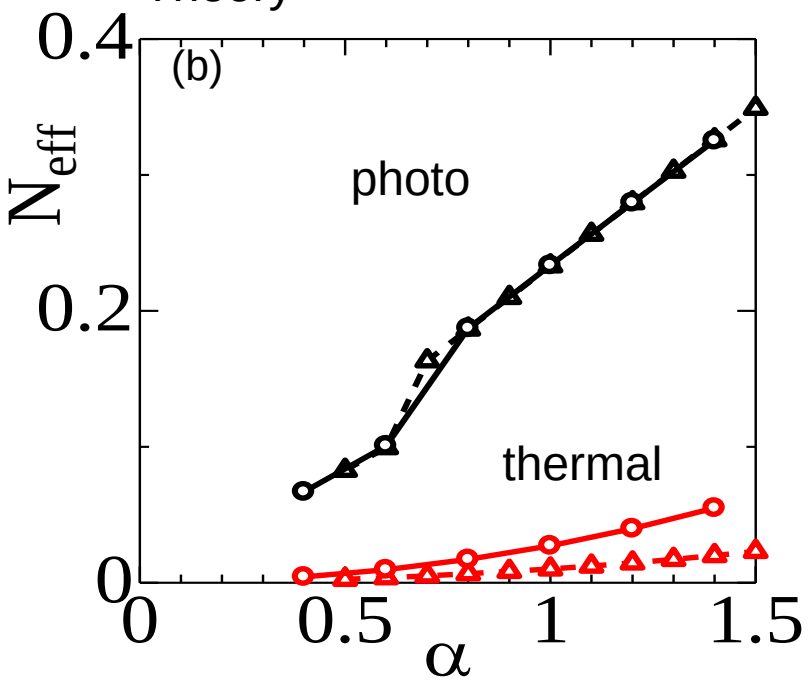
Okimoto-Koshihara

Implication for experiments

Effective optical carrier number

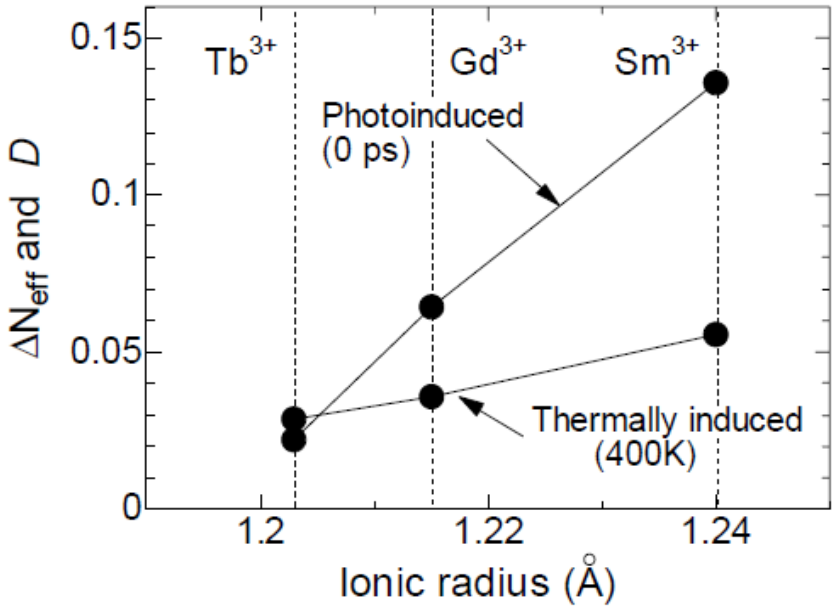
$$N_{eff} = \int_0^{\omega_c} \sigma(\omega) d\omega$$

Theory



Electron transfer

Experiment

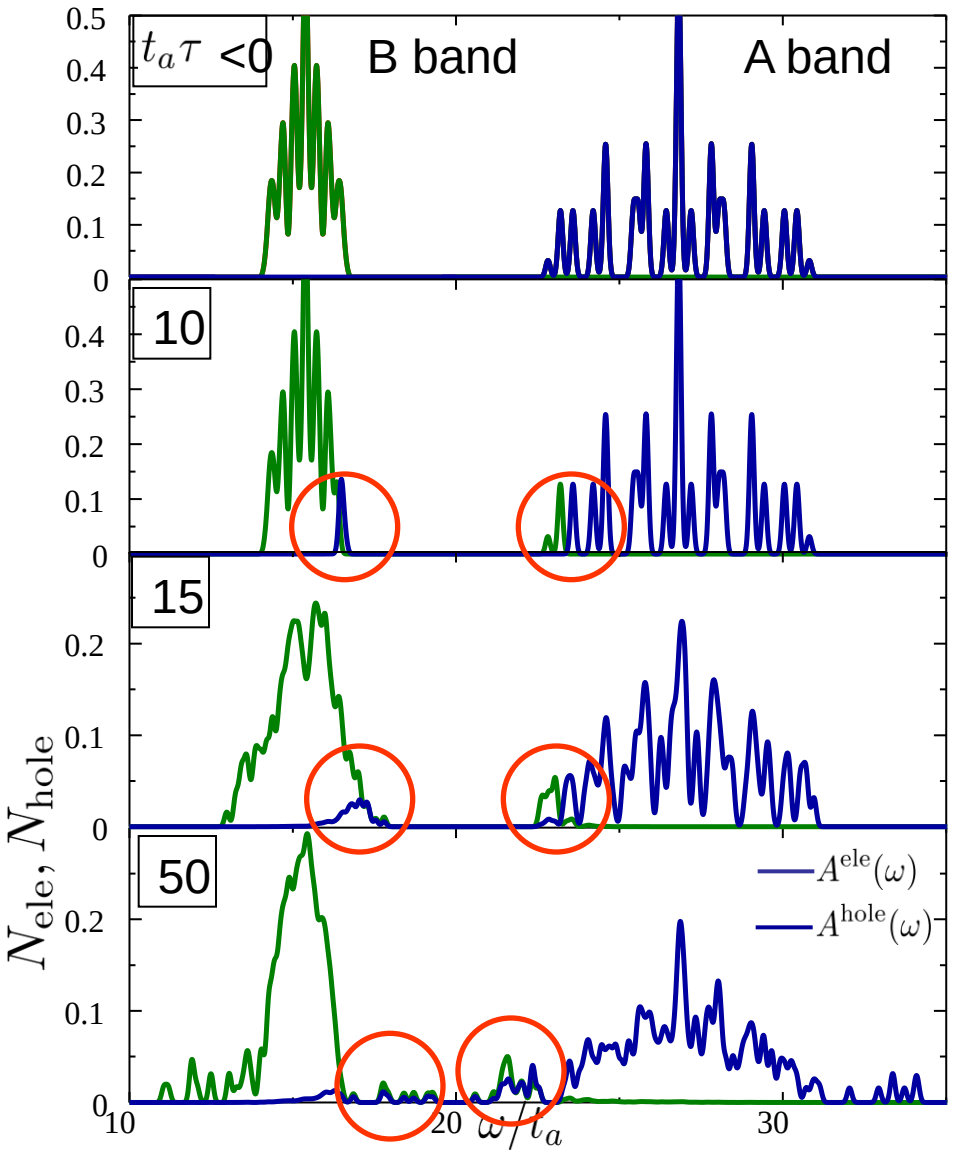


Okimoto-Koshihara

Neff increases with transfer
but
large difference between thermal & photo

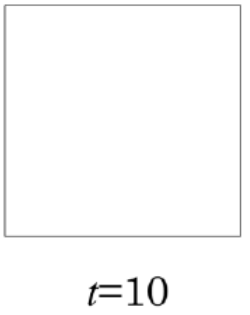
Time Evolution

DOS

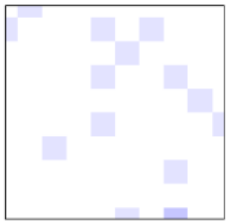


time

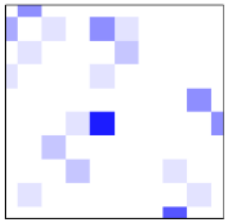
HS map



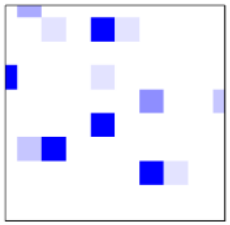
t=10



15



20

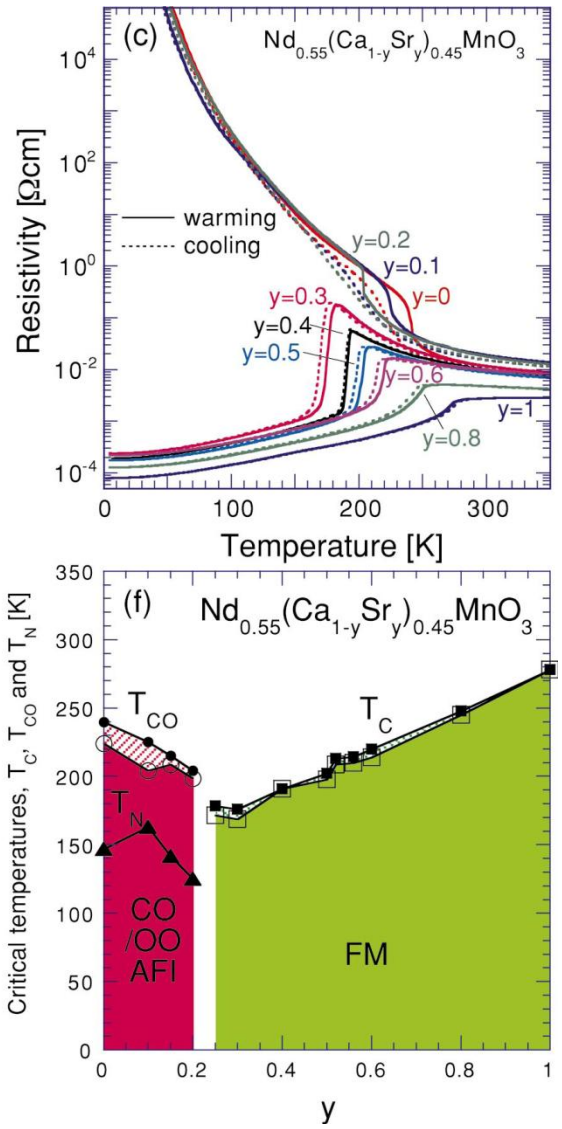


50

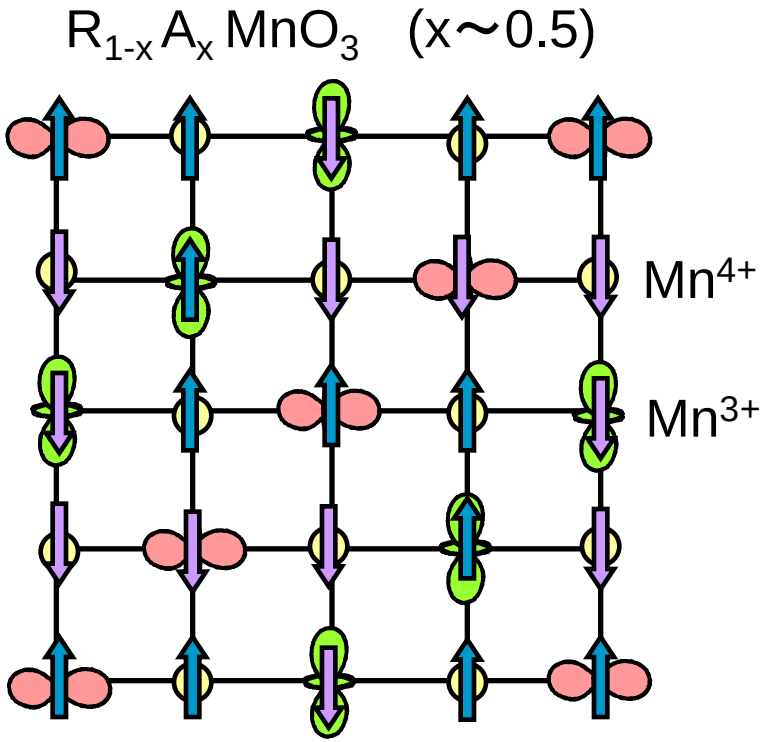
Unconventional photon intensity dependence in Double exchange system

(manganites)

Manganite: as a charge-spin coupled system



Tomioka-Tokura et al. PRB (‘04)

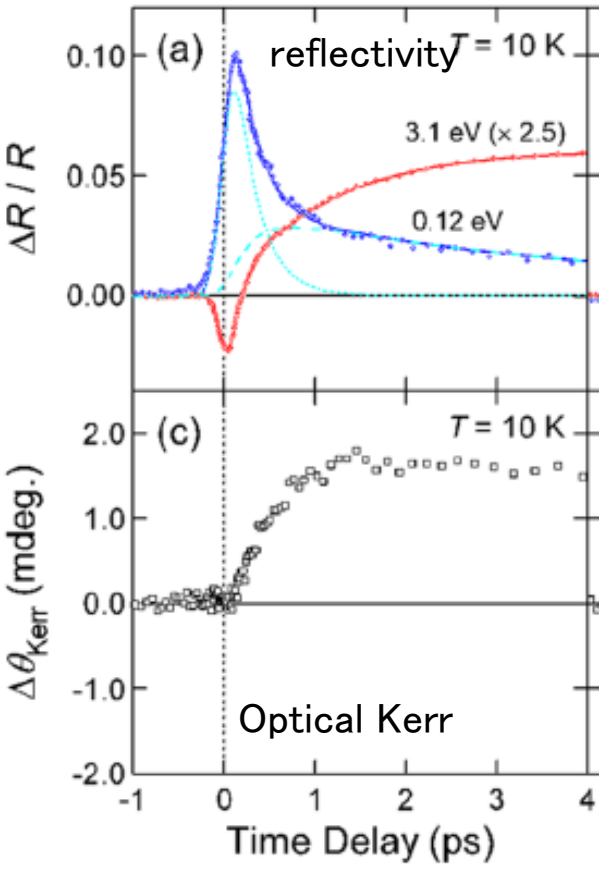


Charge/Orbital/AF
ordered Insulator
v.s.
Ferromagnetic Metal

Colossal Magneto Resistance

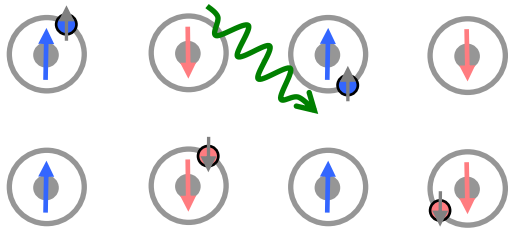
Photo irradiation

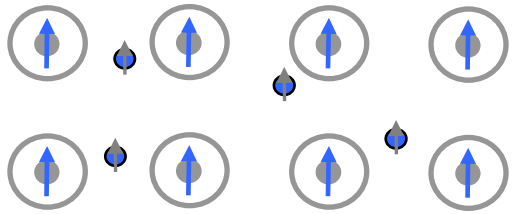
Optical pump-probe



- Photo-irradiation

CO-OO AFM insulator



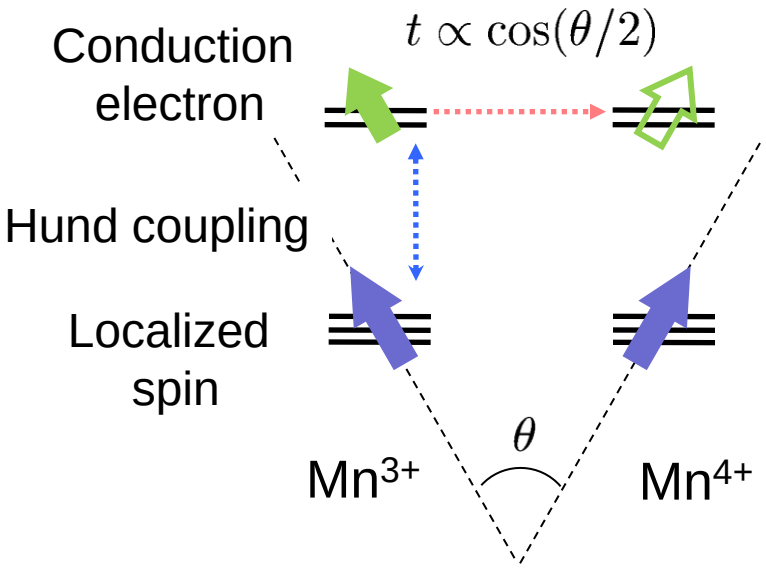


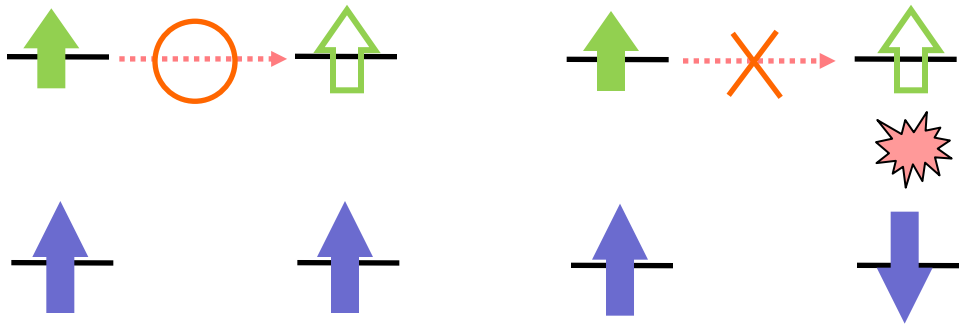
Ferromagnetic metal

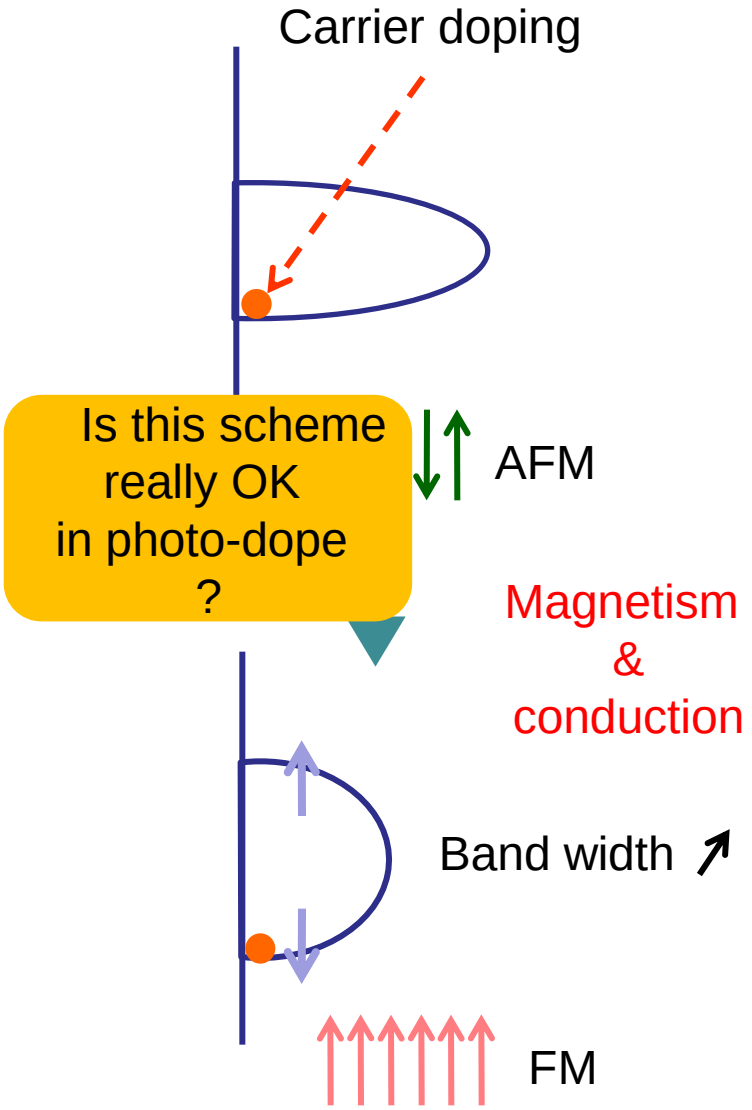
Matsubara et al. Phys. Rev. Lett. (‘07) and many

Double exchange interaction

Zener (‘51), Anderson-Hasegawa (‘55), de Gennes (‘59)



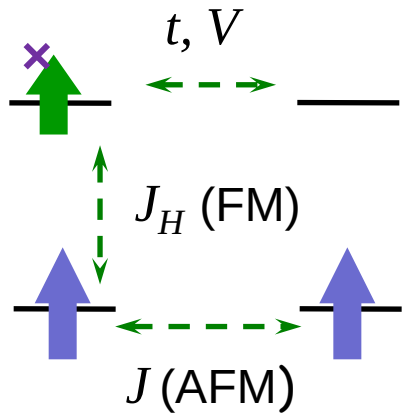




Double exchange model

- double exchange model (ele # / site=0.5)

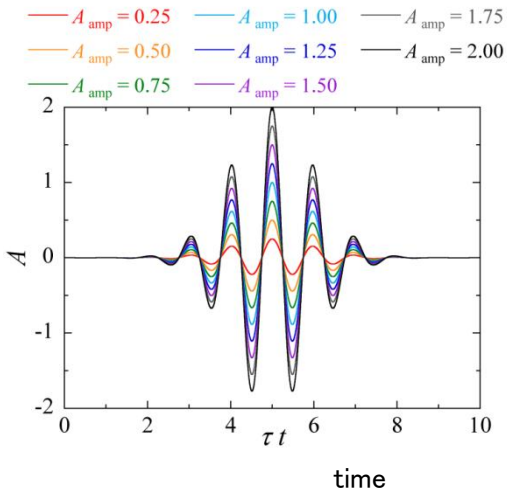
$$\mathcal{H}_{DE} = t \sum_{\langle ij \rangle \sigma} c^{\dagger}_{i\sigma} c_{j\sigma} - \frac{J_H}{2} \sum_{iss'} c^{\dagger}_{is} \vec{\sigma}_{ss'} c_{is'} \cdot \vec{S}_i + J \sum_{\langle ij \rangle} \vec{S}_i \cdot \vec{S}_j \qquad J_H \to \infty + V \sum_{\langle ij \rangle} n_i n_j$$



- Pumping

$$t_{ij} \to t_{ij} e^{-i \int \mathbf{A} d\mathbf{r}}$$

$$A(\tau) = A_{\mathrm{amp}} e^{-\gamma_0^2 (\tau - \tau_0)^2} \cos \omega (\tau - \tau_0)$$

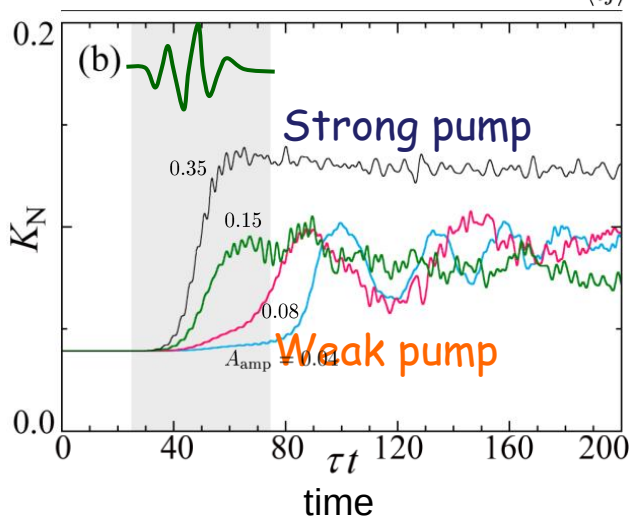


- Exact diagonalization in finite size cluster $(N \leq 25)$
  Schrodinger eq. & Bloch eq.

Charge & spin states

Weak CO correlation

Charge correlation func. $K_N = N^{-1}\sum_{\langle ij\rangle}\langle n_i n_j\rangle$



Strong CO correlation

time

$10\,\pi t$ ~ 20Fs

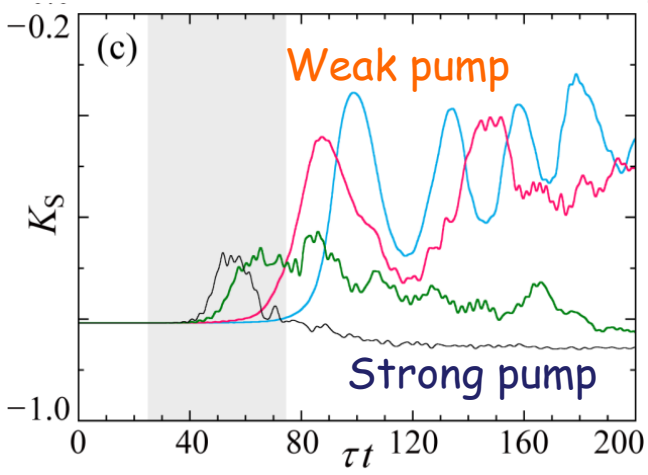
■ Melting of CO

Weak pump: Weak melting

Strong pump: Strong melting

FM

Spin correlation func $K_S = N^{-1}S^{-2}\sum_{\langle ij\rangle}\mathbf{S}_i\cdot\mathbf{S}_j$



AFM

■ Melting of AFM

Weak pump: monotonic melting

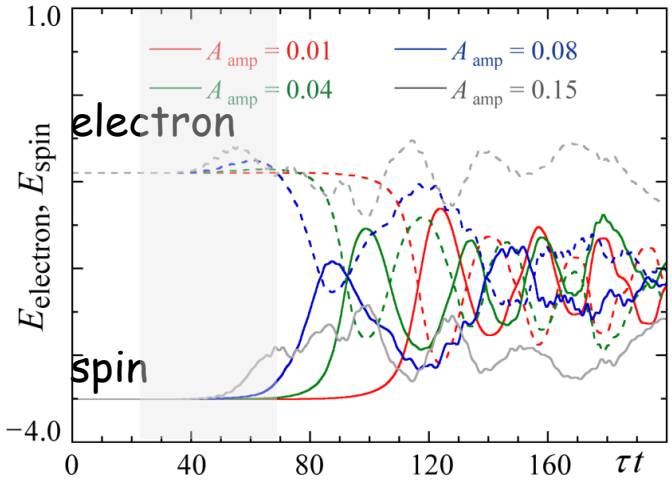
Strong pump: melting in short time
and then
increasing of correlation

J. Ohara Y. Kanamori and SI, arXiv.:12041844

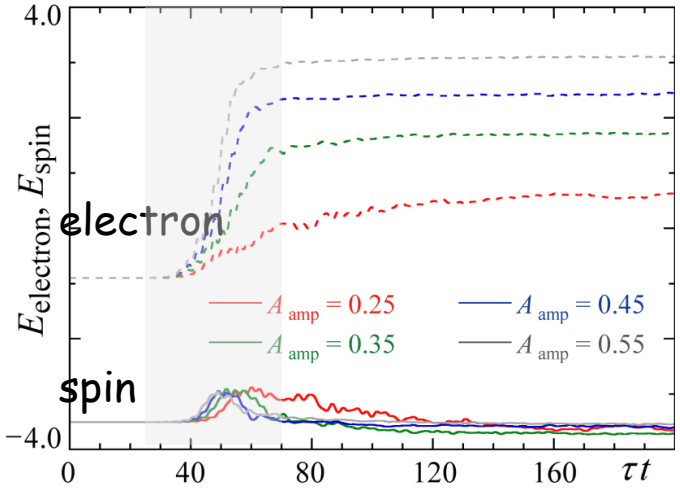
Energy flow

E_{electron} Kinetic ener. + Coulomb ener.. E_{spin} Exchange term

Weak pumping

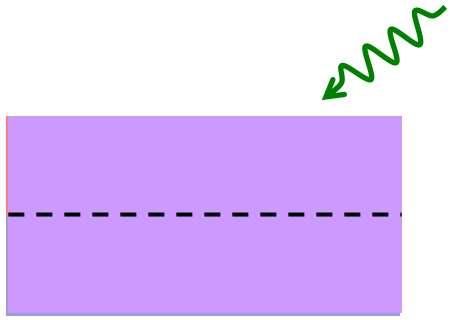


Strong pumping



■ Weak pump

Electron ⟶ Spin

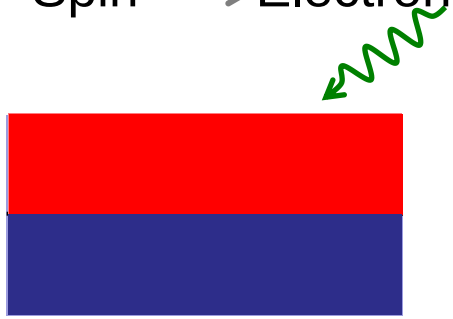


Conduction electron

Localized spin

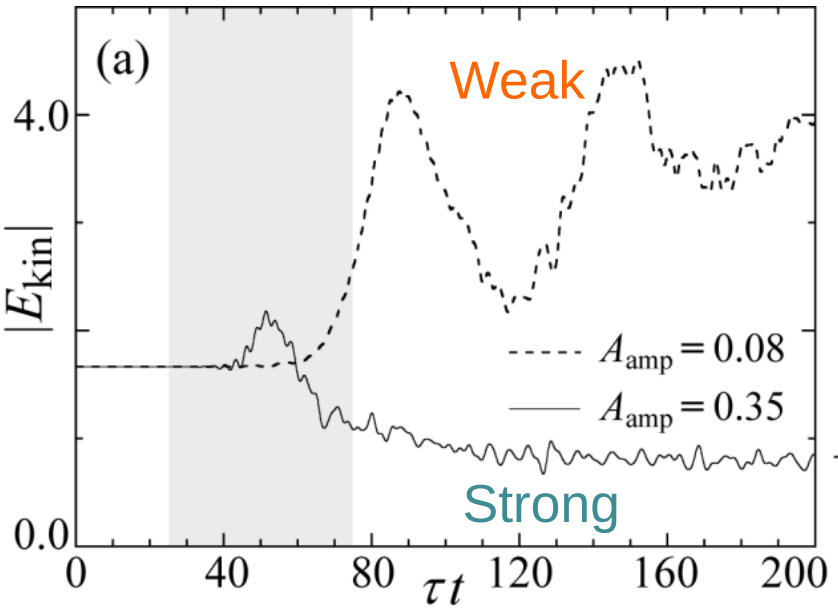
■ Strong pump

Spin ⟶ Electron

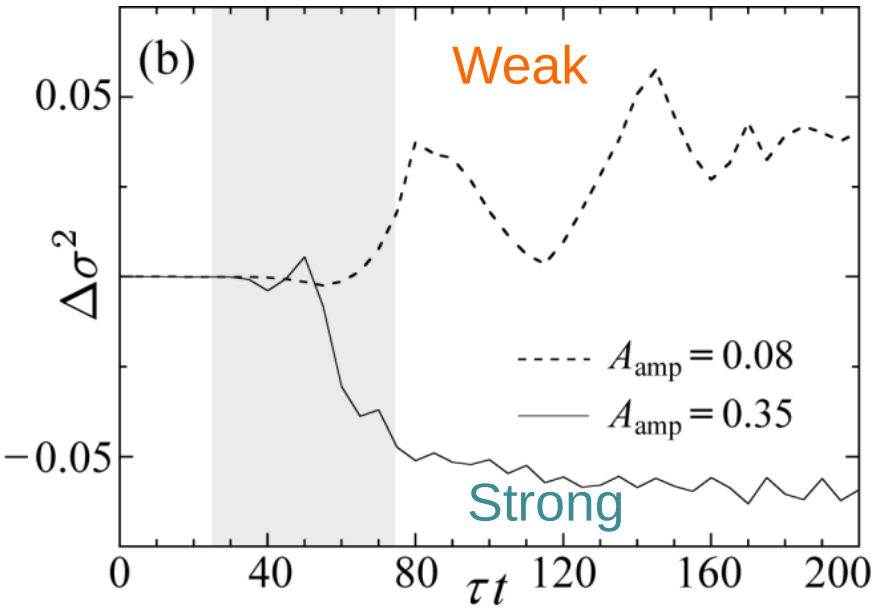


Strong v.s. weak pumpings

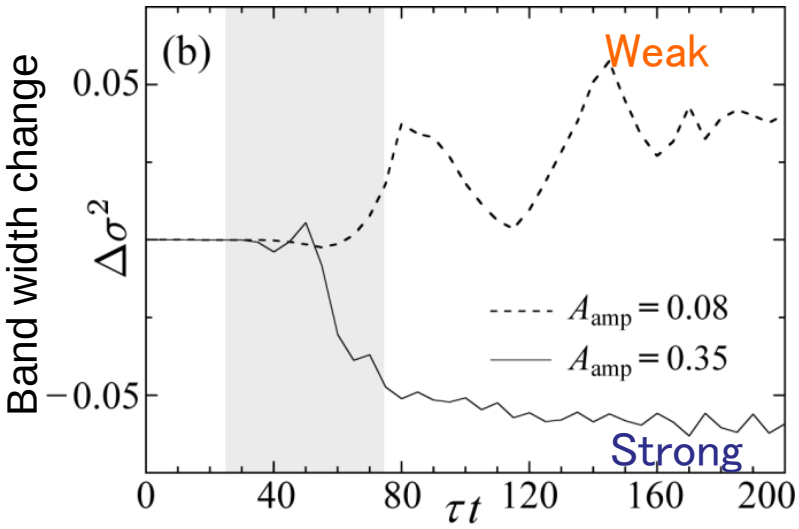
Kinetic energy

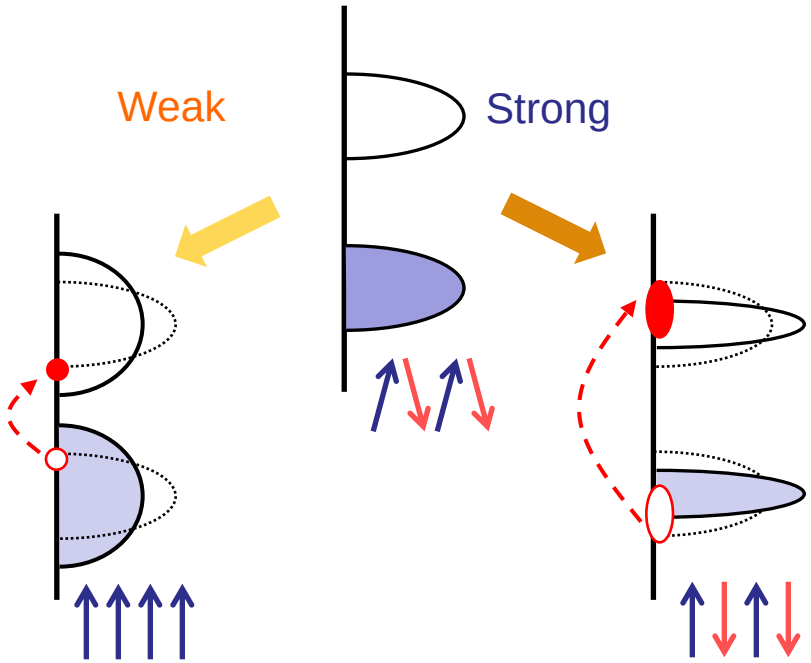


Bandwidth



Optical manipulation of band width & magnetism





Weak : Increasing of W

Cant CO ⟶ FM metallic

（conventional double exchange）

Strong : Decreasing of W

Cant CO ⟶

charge disordered AFM insulator

(Unconventional)

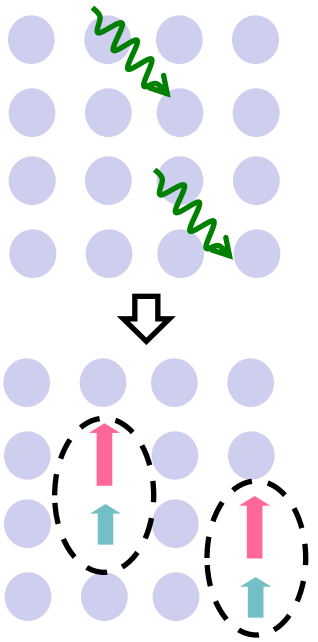
Band width ⟷ Spin

High excited state by photon

J. Ohara Y. Kanamori and SI, arXiv.:12041844

Summary

Optical Manipulation of Magnetism via Double Exchange



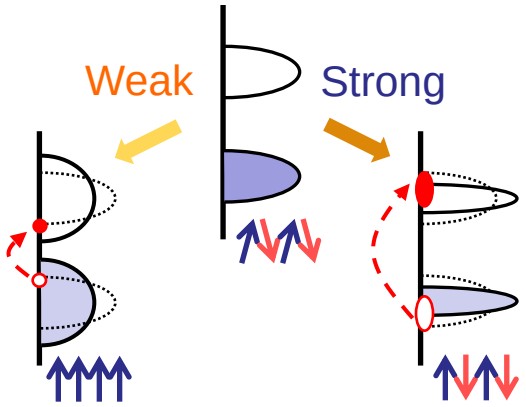
Spin state system (cobaltites)

- Photo-induces spin-state transition
- FM HS-hole bound state
- Much difference from thermal excitation

Y. Kanamori, H. Matsueda and SI, PRL 107, 167403 ('11)
Y. Kanamori, J. Ohara and SI PRB 86, 045137 ('12)

Unconventional double exchange (manganites)

- Anomalous photon-density dependence
- Weak pumping: CO-AFM → FM metal
  (conventional double exchange scenario)
  Strong pumping : Melting of CO but AFM
  (a hidden state)



Y. Kanamori, H. Matsueda and SI PRL 103, 26740 ('09)
Y. Kanamori, H. Matsueda and SI, PRB 82, 115101 ('10)
J. Ohara Y. Kanamori and SI arXiv.:12041844